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Application of 3D Printing Technology in Customized Equipment Manufacturing for Cycling

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Abstract. Bicycles are important vehicles, whose monolithic constructions and components and parts are continuously and necessarily iterative upgrading to satisfy the diversified and personalized needs of Ordinary cyclists and professional athletes. Therefore, with the advantages like short cycle, good flexibility, strong adaptability, and customization of the 3D printing technology, there is an increasing number of its applications in the personalized markets, and compared to the traditional processing techniques, it has incomparable advantages. The focus of this essay begins with the emblematic 3D printed customized cycling equipment, such as brake ducts, metal parts, saddles, handle covers, and helmets. From this, the essay derives some general problems with the current 3D printing technology in the manufacture of customised equipment for cycling, namely the limited production scale, the high costs of the manufacturing, and the limitations of material properties and processing technic, the corresponding possible future directions namely the scale and distributed production, intelligent and data-driven manufacturing and material innovation and multi-material fusion.

Keywords: 3D printing technology, customized equipment, cycling equipment.

1. Introduction

As one of the most important vehicles, bicycles, with the advantages like convenience, energy saving, and low carbon emissions, are widely promoted in most countries and loved by cyclists. Moreover, many competitive events use cycling as a major tool.

The monolithic constructions, components, and parts of bicycles are continuously iteratively upgraded to satisfy the diversified and personalized needs of most types of cyclists. However, traditional bicycles are mostly manufactured and assembled in batches; most of their parts are the same or in the same series, which can not meet the needs of some cycling enthusiasts commendably, especially professional athletes.

In competitive sports, the deviation of a part of cycling equipment from the physical conditions will affect the psychological and physiological conditions of athletes, which will probably affect the final results of the competitions. This group of cyclists has specific needs and specifications for cycling equipment. Therefore, it is of great significance to develop customized equipment manufacturing for cycling.

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With the rise of 3D printing technology with additive material as a significant feature, customised equipment manufacturing meets a new process technology direction. Due to the advantages like Short cycle, good flexibility and strong adaptability of 3D printing technology in the manufacturing industry, there is an increasing number of its applications on the personalized markets. Many parts which can be created on the 3D printers can, however not be made by any known conventional machining techniques [1]. Therefore, compared to the traditional processing techniques,3D printing technology has incomparable advantages in the field of customised equipment manufacturing,so does the development and application in the cycling customised equipment area. Related companies have manufactured 3D printed frames [2], 3D printed helmets [3], 3D printed polyurethane bicycle saddles [4], and other derivative products for more than a decade.

Now, 3D printing technology has been greatly developed in the field of customized equipment manufacturing for cycling. In the future, further research on 3D printing technology in this field will be conducive to improving the bicycle body structure and the iterative upgrade of other cycling equipment, so that both professional athletes and ordinary enthusiasts can have a better personalized cycling experience, while reducing material waste.

This paper mainly discusses the advantages of 3D printing technology in the field of customized equipment manufacturing for cycling, representative customized cycling equipment, and existing problems, and puts forward suggestions and opinions on the development direction of 3D printing technology in the field of customized equipment manufacturing for cycling in the future.

2. Brake ducts

2.1. The need for customization

Brakes play a vital role in controlling speeding vehicles, as in bicycles [5]. Bicycle brakes suffered from extreme heating during descents and emergency stops, especially in high altitude or temperature conditions, and that will lead to overheating and brake fluid boiling, which reduces braking efficiency [6].

Ioan I. Feier and Aaron P. Bauer’s CFD simulations and downhill tests showed that the best duct increased heat transfer rates from the disk and caliper by 5% and 20%, respectively, compared to no ducts [6]. That result indicated that strategically designed ducts can enhance brake cooling, and that will make the braking system more efficient.

2.2. The advantages

Strategically designed ducts can channel airflow directly to brake components. This will not only improve heat dissipation but also reduce the risk of overheating. This targeted cooling improves performance and prolongs the lifespan of brake components, ensuring consistent braking under demanding conditions [6]. Additionally, brake ducts can reduce wetting of disks and pads during rain and help prevent fouling in off-road and muddy conditions. Enhanced braking capability is crucial for modern hydraulic brakes on both conventional bicycles and contemporary electric bicycles used for commuting and recreation [6].

Limited duct shaping options and additional design restrictions ensured compatibility with consumer 3D printers. Once cyclists and racers have found a suitable design, they can use 3D printing to create ducts at home. This efficient, rapid, low-cost manufacturing, bring superiority that traditional processing techniques cannot reach [6].

DOI: 10.54254/2755-2721/2025.GL28345

2.3. Manufacturing process overview

According to Ioan I. Feier and Aaron P. Bauer's research [6], they use the modular approach to test the cooling duct and aerodynamic characteristics, which can quickly identify the optimal configuration. Use CAD to create modular ducts designed to enhance the front hydraulic brake cooling of a mountain bike. The subsequent research will focus on optimizing the shape design of the bike brake duct to further improve the heat dissipation performance.

3. Topology optimised metal parts

3.1. The need for customization

The traditional method is almost impossible to achieve the manufacturing of metal parts with complex geometry, which is mainly limited by the limitations of tooling constraints. However, Additive Manufacturing (AM) or 3D printing technology has broken through the limitations of traditional manufacturing, and while the constraints imposed by traditional manufacturing are not applicable to AM, it has become an ideal solution for such parts [7].

3.2. The advantages

Metal 3D printing, which is commonly referred to as metal additive manufacturing, is a process using metal alloys and metal 3D printing technologies applied to produce metal parts. This technology has the advantages of less waste of raw material, design freedom, manufacturing of near-net-shape parts, manufacturing of topology optimised complex geometries, lattice structure, and mass customisation [8].

In conclusion, MAM is a growing field providing many possibilities for manufacturing advanced or complex parts that are difficult to manufacture using traditional methods. MAM also makes such parts closer to the point of usage and thereby improves the convenience of customization and usage [7].

3.3. Manufacturing process overview

According to Arora's five stages before formulating a topology optimisation-based design workflow, Tajudeen A. Sulaymon et al proposed the following specific steps for a certain load-bearing capacity using a topology optimisation [7].

First, use Finite Element Analysis (FEA) to understand the stress and displacement distribution across a part. Second, a topology optimization tool uses this information to remove some unnecessary materials from a part. Topology optimization steps start typically with a basic 3D model, then a set of loading and boundary conditions is specified for the 3D model, and then the topology optimization software optimizes the model. The optimised part mesh is cleaned, and a second round of FEA might be carried out to meet the requirements specifications.

4. Saddle

4.1. Main types

There are currently two types of bicycle seats available: one is a narrow, elongated hard saddle, which is commonly found on exercise bikes and is designed for professional cyclists; the other is a

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wide and soft comfort seat saddle, which is commonly found in entry-level bikes or leisure-oriented bikes, and is designed for the daily use of ordinary cyclists.

4.2. The need for customization

Regardless of the types of saddles (except for those used by high-level professional cyclists), they are mass-produced and put on the market, with the same model and uniform specifications. These products fail to account for individual differences in riders' body types, hip measurements, or primary pressure points during cycling. As a result, cyclists often experience discomfort in their buttocks and friction between thighs and saddle surfaces, which can lead to lower back pain and other issues [9]. Therefore, it is necessary and promising to customize personalized saddles according to the physiological conditions and individual needs of different cyclists.

4.3. Customized processes overview

According to Wang Xinqing, after defining the overall programme, there are mainly three steps to make a customized saddle in her project [9].

The first step is a hip scan. According to the size of different people's hip shape, obtained three-dimensional data of the hip was obtained. Next, create a custom saddle model. Based on the 3D scanning data of the hip shape point cloud, use the software Geomagic Studio to remove invalid points, correct valid points, then smooth the model curves, and establish a three-dimensional custom saddle model. Complete the creation of the 3D custom saddle model using 3D modeling software such as UG, Pro/E, and SolidWorks.

Eventually, print a customized saddle. Her project uses light-sensitive resin(ABS) as the printing material. Through 3D printing technology, the created 3D model of the customized saddle undergoes format conversion and slicing processing. After being imported into the 3D printer, the customized saddle is printed.

5. Handle cover

5.1. The need for customization

The handle cover is a component installed on the bicycle handlebar tube. Its main function is to increase the handling performance and comfort of the handlebars. The particle size, tightness, and surface roughness of the handle cover will have a certain impact on the tactile sensation of the rider's hand, which is likely to affect the riding experience.

5.2. Shape and comfort

The bicycle handle covers sold in the market are mainly divided into straight cylindrical type and bionic design type, with or without corners [10]. An ordinary straight cylindrical shape is easy to form unnatural grip mode, easy to cause discomfort in the palm and wrist bone; The ergonomic bionic design can increase the contact surface between the palm and the handle covers to obtain a natural and correct support state, which can effectively relieve local pressure and make the rider's grip more comfortable [10].

If this kind of bionic design type handle covers can be tailored to the individual hand characteristics and personalized needs of cyclists, such as the personalized needs of professional athletes in competitions, it can improve the comfort of cyclists and enhance the cycling experience.

DOI: 10.54254/2755-2721/2025.GL28345

5.3. Customized processes overview

According to Zhu Xiaoming, et al, the main steps are as follows [11]. The first step is initial modeling and 3D printing. This means referring to the existing handle size, the prototype structure of the existing handle is imitated to design the initial sample model. What needs to be noted is that the overall size of the model is 5 ~ 10 mm smaller than the outer contour line of the actual product, so as to leave room for the operation of surface contour repair and adjustment in the subsequent oil clay model making. Use SolidWorks modeling to determine the overall contour of the model, control the general size of the model, layout the key structural points for the overall shape, and construct the rough spatial curve. Then use the drawing and scanning functions to construct the preliminary surface shape.

Second, make an oil mud model. Use the 3D printed prototype model as the skeleton for making an oil clay model. Oil mud is applied to the 3D printed part, and roughly scraped off. By means of vision and touch to inspect and correct the curved surface of the handle cover during this process, to improve the product details, and finally obtain the handle cover model with a comfortable grip.

The third step is 3D scanning and surface reconstruction. According to Zhu xiaoming et al, they used the Wiiboox Reeyee Pro 2X handheld white light 3D scanner to take non-contact measurements of the clay model and obtain its point cloud data. After stitching and fusing multiple scans of point cloud images to obtain the triangular mesh data of the model, the model undergoes smoothing optimization. Finally, an STL-format model for the sleeve is created and exported. Then import the STL model into Geomagic Wrap software for point cloud processing and surface reconstruction.

Finally, redesign the product. Imported the reconstructed surface model into SolidWorks software for redesign, mend the surface gap, and stitch the surface to form a solid. Then, I processed the feature details.

6. Helmet

6.1. The need for customization

Personalization stands as a defining trend in the future of athletic helmets. Current advancements have already enabled customized designs for both visual aesthetics and functional configurations. These include user-tailored helmet appearances with personalized color schemes, cushion layers, and padding optimized through head data analysis, and aerodynamic shells engineered according to specific sports postures. In the future, developing specialized protective gear tailored to unique athletic demands will emerge as a key research focus in this field [12].

6.2. The advantages

Personalized sports helmets are consistent with users' functional requirements due to their wearing comfort, aerodynamic performance, and other performance, but the traditional manufacturing such as mold injection molding, is too much. 3D printing technology has high adaptability to the change of digital models, and has become the main manufacturing technology for personalized sports helmets [12]. In terms of personalized manufacturing, 3D printing technology can design helmet lining matching the head shape of athletes according to the head contour of athletes, so as to improve the comfort of helmet wearing [13].

DOI: 10.54254/2755-2721/2025.GL28345

6.3. Customized processes overview (HEXR3D Printing Company as an example)

Customers provide their head data online, and then HEXR engineers use that data to design a customized dot matrix structure buffer. The design of the buffer layer is to use a 3D scanner to obtain head data, and the use of software design to fit the head data with a honeycomb dot matrix buffer layer, which is then manufactured using SLS technology, and finally delivered to the customer [14].

7. General problems with the current 3D printing technology

7.1. Limited production scale

At present, the implementation of 3D printing technology based on customization and personalization in the field of cycling equipment has been verified.

Although 3D printing technology has obvious advantages in personalized customization, its manufacturing precision and processing speed are far from meeting the goal of producing sports equipment.

The core contradiction lies in the essential opposition between "customization" and "scale".As it is a customized production, the status monitoring of each equipment, material supply, retrieval and post-processing process scheduling is different, which is far more complex than managing a traditional injection molding line, and requires high requirements for production management software and automation system.

While traditional injection molds are expensive, their costs are spread across tens of thousands of products, resulting in extremely low per-unit expenses. 3D printing eliminates mold costs entirely, but the unit cost per product (including machine depreciation, materials, labor, and energy consumption) remains nearly constant. This makes it difficult to achieve significant reductions through increased production, as economies of scale cannot be effectively realized.

7.2. High manufacturing costs

The problem goes far beyond "machines and materials are expensive"; the high cost is across the entire industry chain.

In terms of equipment investment, 3D printers that are capable of producing high-performance cycling gear, such as carbon fiber reinforced nylon helmets and titanium alloy bicycle parts, are expensive industrial-grade devices. In terms of material cost, the form of 3D printing materials must be suitable for specific processes, such as powder with precise particle size, wire with specific diameter, and the preparation and processing cost is significantly higher than that of traditional manufacturing materials. In addition,3D-printed parts are usually "rough" and must be post-processed before they can be used. This is the most underrated but expensive and time-consuming part of the process, such as support removal and cleaning.

7.3. Material properties and process limitations

Cycling equipment(such as helmets) needs to withstand thousands of cycles of load (vibration, pedaling, impact). Currently, the mechanical properties of some 3D printing materials (such as impact resistance and fatigue resistance) are still inferior to those of traditional manufacturing materials. What's more, the interlayer bonding strength of 3D printing is usually lower than the strength of the material itself within the layers; this may affect the durability of products, especially

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in high-load cycling equipment (such as frames and helmets).In summary, these three issues are interconnected: Material properties and process limitations (Issue 3) hinder their adoption in mainstream high-end applications, preventing scaling (Issue 1). The inability to scale, in turn, drives up unit costs (Issue 2), which in turn discourages more funding for R&D to address both material limitations and scalability challenges.

8. Possible future directions

8.1. Scale and distributed production

Develop industrial-grade 3D printing clusters and integrate localized manufacturing models. To achieve large-scale personalized production of customized cycling equipment, the development of more efficient 3D printers and more scientific production models will become the focus of future research.

To achieve economies of scale in customization, "modular customization" emerges as a solution. For instance, a custom bike frame might be designed with modular components like the front triangle, rear triangle, seat post clamp, and interface kits. Users only need to customize the critical front triangle section, while the rest can utilize standard parts or limited customization options. This approach allows printing centers to concentrate resources on producing the most complex core modules, while other components can be swiftly sourced from traditional supply chains. This methodology effectively balances customization needs with operational efficiency.

8.2. Intelligent and data-driven manufacturing

Combined with AI algorithm optimization and customization design, such as dynamically adjusting the seat support structure through cycling big data. AI algorithms leverage multidimensional data, including human anatomy, biomechanical principles, and personal preferences, to achieve multi-objective optimization. For example, when designing a handle cover, the AI simultaneously optimizes four key metrics to find the optimal solution. Minimum weight; 2) Minimal deformation under specific pedaling forces; 3) Aerodynamic compliance; 4) Optimal wrist pressure distribution.

Using digital twin technology (such as Siemens' solution for HEXR) to simulate product performance and shorten the R&D cycle. Finite element analysis (FEA), computational fluid dynamics (CFD), and fatigue life simulation are performed in the virtual environment prior to physical printing.

8.3. Material innovation and multi-material fusion

Develop 3D printing materials with higher strength, lightweight, and environmental adaptability, such as bio-based polyamides (HEXR), self-healing polymers, etc. Combine multiple materials (e.g., carbon fiber + titanium alloy) to achieve functional integration, for example, the integrated printing of energy-absorbing layers and rigid shells in helmets.

9. Conclusion

With the increasing development and maturity of 3D printing technology, as well as the increasingly diversified personalized needs of cyclists for cycling equipment, 3D printing technology has been more and more widely and deeply applied in the manufacturing of customized cycling equipment. Through the analysis of the above typical applications, we can find that compared with traditional

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processing technology, 3D printing technology has unique advantages in the field of customization, such as customization, high design freedom, short technical cycle, good flexibility, and strong digital adaptability, which are in line with the needs of customized equipment. However, 3D printing technology is limited in production scale and some costs are relatively high, making it impossible to achieve large-scale production in the field of equipment manufacturing. The possible future development direction will also be oriented to solve these problems, and it may achieve scale and intelligence.

References

[1] Pieterse, F. F., & Nel, A. L. (2016, April). The advantages of 3D printing in undergraduate mechanical engineering research. In 2016 IEEE Global Engineering Education Conference (EDUCON) (pp. 25-31). IEEE.
[2] Nickels, L. (2014). 3D printing the world's first metal bicycle frame. Metal Powder Report, 69(2), 38–40.
[3] Qingfeng. (2019). 3D printed customized bike helmet Hexo emerged. China Bicycle, (01), 80.
[4] Specialized and Carbon develop 3D-printed urethane bike saddles. (2019). Polyurethane Industry, 34(05), 24.
[5] Feier, I. I., & Bauer, A. P. (2024). Enhancing bicycle brake cooling with 3D-printed modular ducts. Sports Engineering, 27(2), 36.
[6] Sulaymon, T. A., Helo, P. T., & Toshev, R. (2022). Towards a complex geometry manufacturing: A case study on metal 3D printing of topology optimised bicycle parts with lattices. *IFAC-PapersOnLine, 55*(10), 1515–1520.
[7] Bourell, D. L., Beaman, J. J., Leu, M. C., & Rosen, D. W. (2009). A brief history of additive manufacturing and the 2009 roadmap for additive manufacturing: Looking back and looking ahead. Proceedings of RapidTech, 24–25.
[8] Wang, X. (2020). Customized bicycle seat cushions based on 3D printing technology. Southern Agricultural Machinery, 51(07), 26–28.
[9] Zhu, X., Zhang, P., & Han, W. (2021). 3D printing customization of bicycle handlebars. Engineering Plastics Application, 49(01), 81–85+101.
[10] Yuan, X., et al. (2024). Discussion on the standard of bicycle handlebar covers and handlebar grips. Light Industry Standards and Quality, (03), 26–28.
[11] Zhu, X., Zhang, P., & Han, W. (2021). 3D printing customization of bicycle handlebar covers. Engineering Plastics Application, 49(01), 81–85+101.
[12] Chen, S., et al. (2022). A review of 3D printing manufacturing technology for personalized lightweight sports helmets. Mechatronics Engineering Technology, 51(11), 31–37.
[13] Jiang, M., Chen, J., & Yan, J. (2017). Research on personalization and lightweighting of winter Olympic helmets for 3D printing technology. Applied Lasers, 37(3), 424–429.
[14] Zhang, J., Luximon, Y., Shah, P., et al. (2022). Customize my helmet: A novel algorithmic approach based on 3D head prediction. Computer-Aided Design, 103271.